FLORIDA SHORE & BEACH PRESERVATION ASSOCIATION
A League of Cities and Counties on Beach and Coastal Issues

Sensitivity Of Occurrence Frequency Of Storm Tide Elevation To Random Tidal Phases In Macro-Tidal Area

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Outline

- Motivation
- Methodology
- Results
- Discussion

Motivation

To determine the percent-annual-chance water level (PWL) in coastal region is critical for coastal design, flood prevention, risk assessment etc.

This study focuses on US upper mid-Atlantic region that are subject to

- Tropical Storms
- Extratropical Storms

Image credit: http://www.dtcc.com/annuals/2013/superstorm-sandy-recovery/index.php

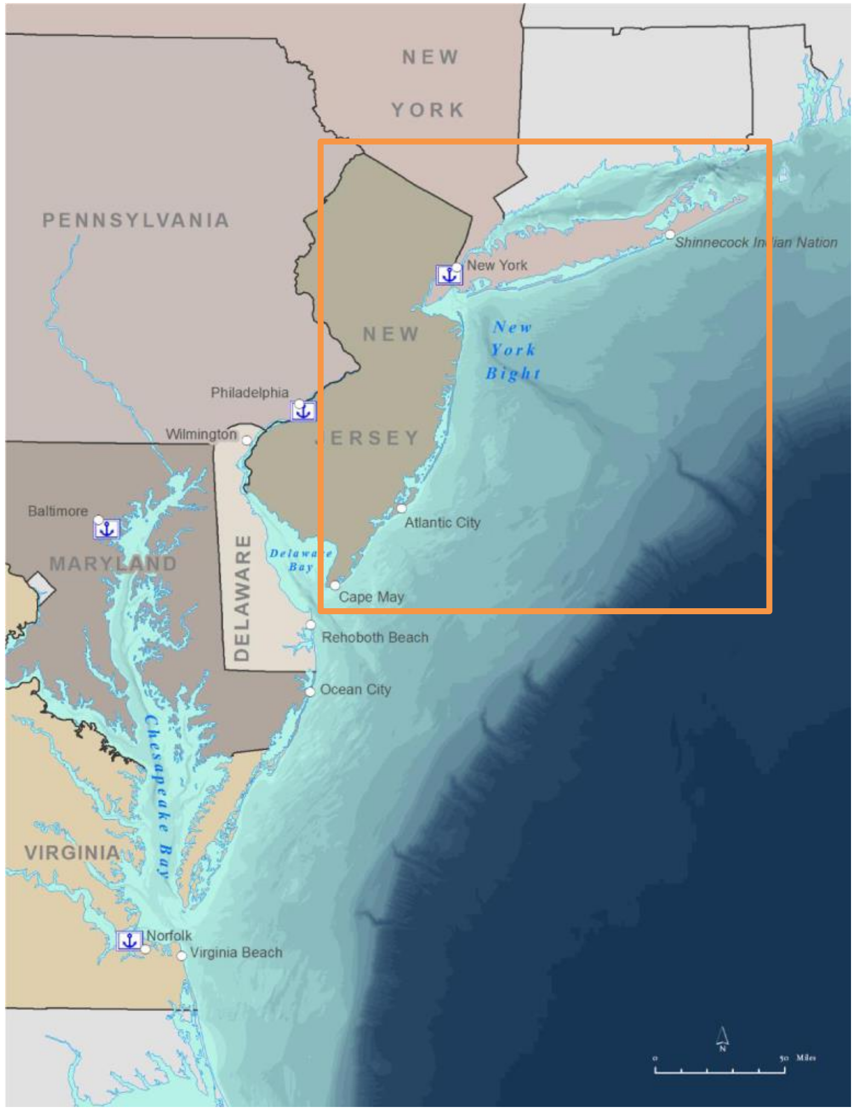

Image credit: http://roa.midatlanticocean.org/

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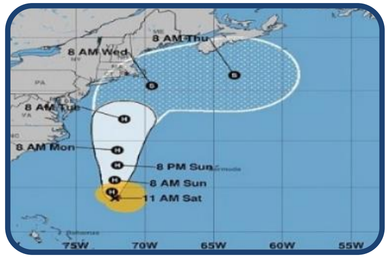
Challenge I – Tropical vs Extratropical Storms



Tropical Storms (ET)

> rapid and strong

> characterized by path, sustained wind speed, pressure etc.

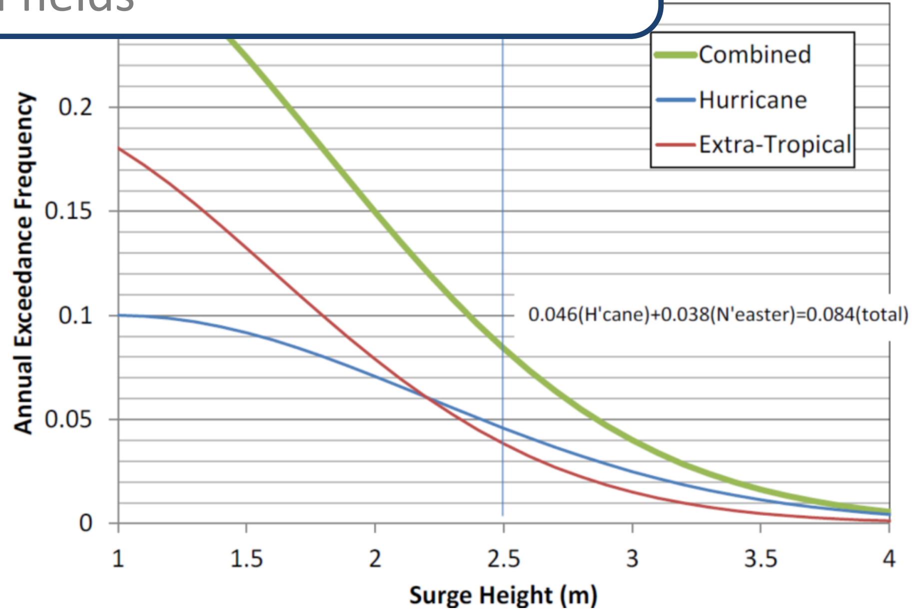
> synthetic storms can be generated using JPM-OS method

Extratropical Storms (ETS)

> long duration

> difficult to characterize the meteorological conditions

> require actual pressure and wind fields



Challenge II – Influence of tide (ETS)

The determination of the PWL at regional scale relies on numerical modeling

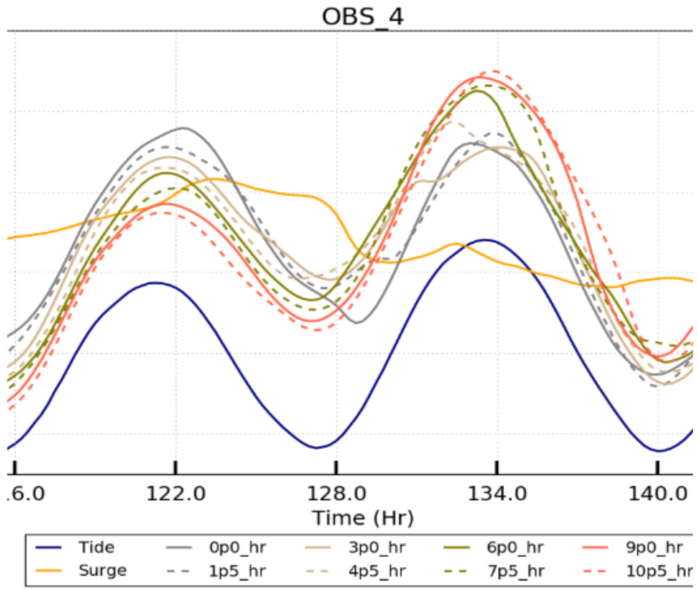
- **Storm selection using peak over threshold analysis**
  non-tidal residuals should be used since
  weak storm at high tide ⇔ strong storm at low tide
- **Storm surge modeling at random tides**
  Storms are independent events of tide
- **Return period analysis (with Q-Q optimization)**
  Remove weak storm due to regional storm selection

How the PWL will change should peak storm surge occur at different tide conditions? Specifically,

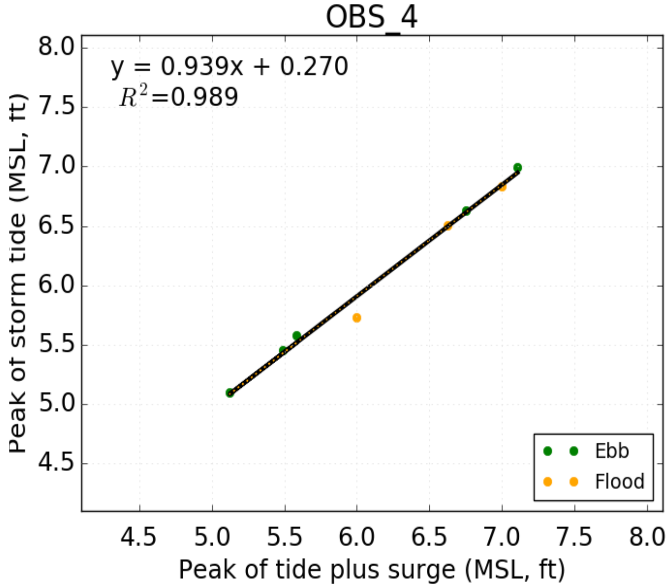
1. What is the variability of the PWL associated with the random tide selection for each storm?
2. What is the number of tide required for each storm to reduce the aleatory bias (variability) of the PWL introduced by random tide?

Methodology

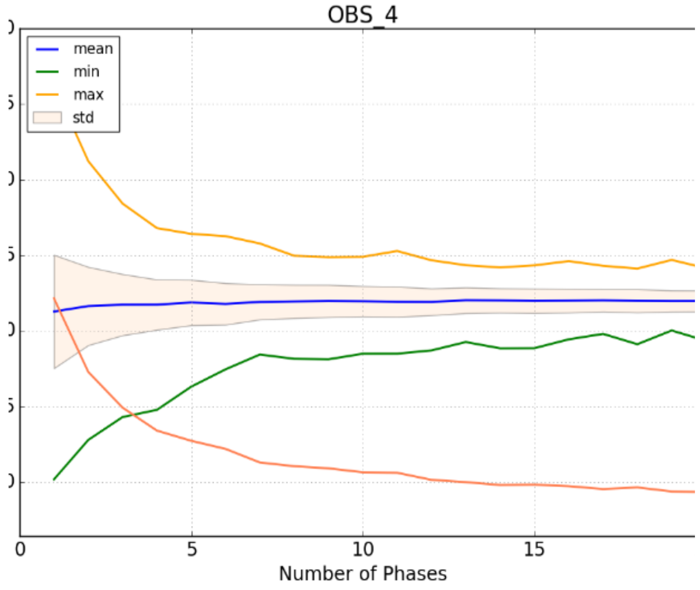
Tide, Surge, and Storm Tide



Nonlinearity



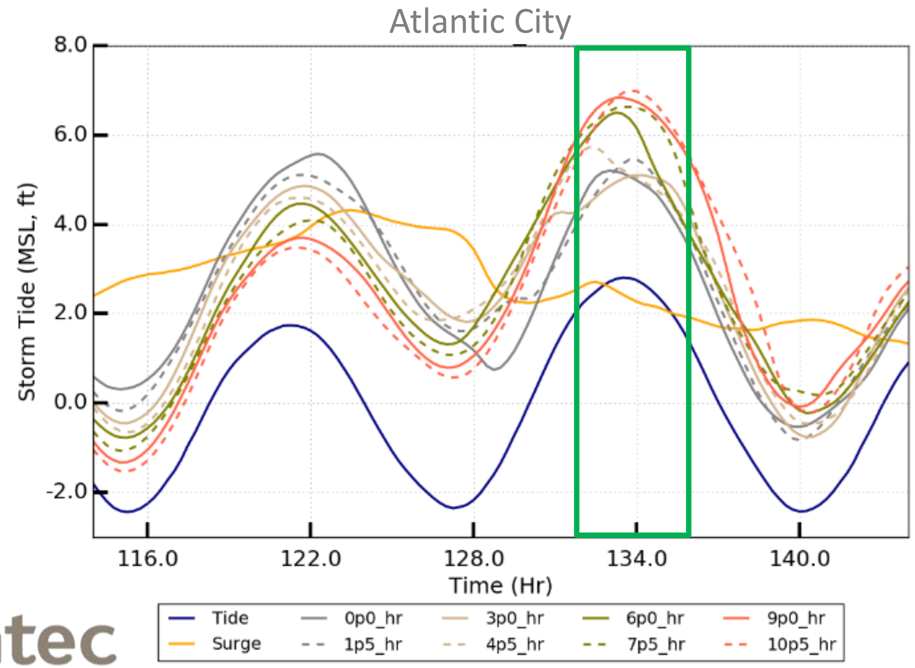
Bootstrapping

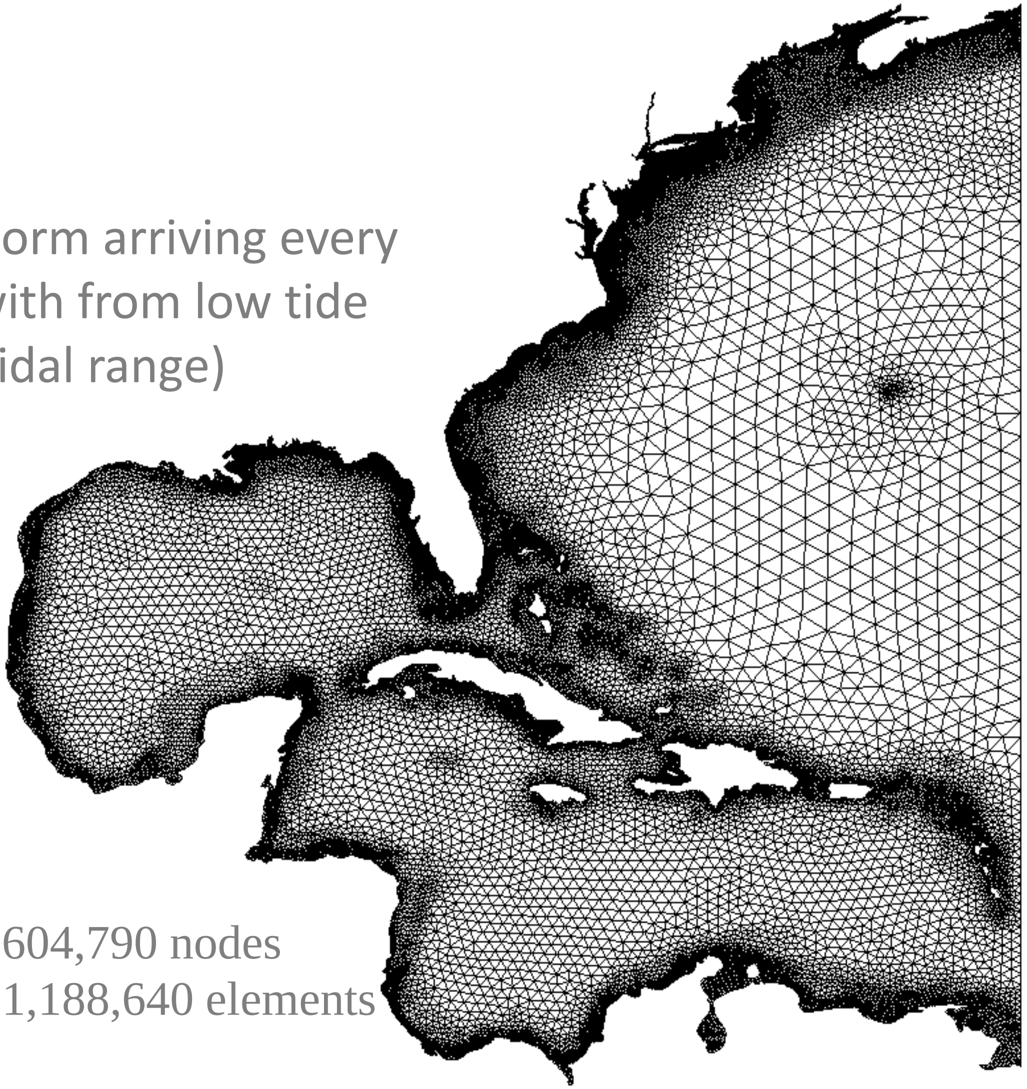


ADCIRC model from FEMA Region II study

30 historical extratropical storms; focus on 1974 storms for analysis of storm tide as a function of tide

- Tide only simulation
- Surge only simulation
- Six storm tide (tide+surge) simulations with each storm arriving every 1.5 hour with peak surge (***not*** the WL) coincident with from low tide to high tide (typical spring tide to provide a larger tidal range)





604,790 nodes
1,188,640 elements

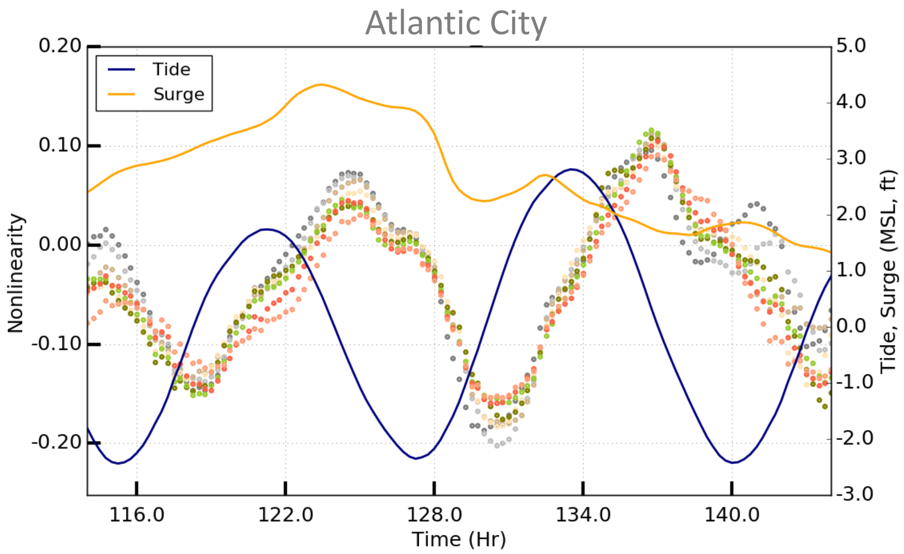
Linear superposition vs direct simulation

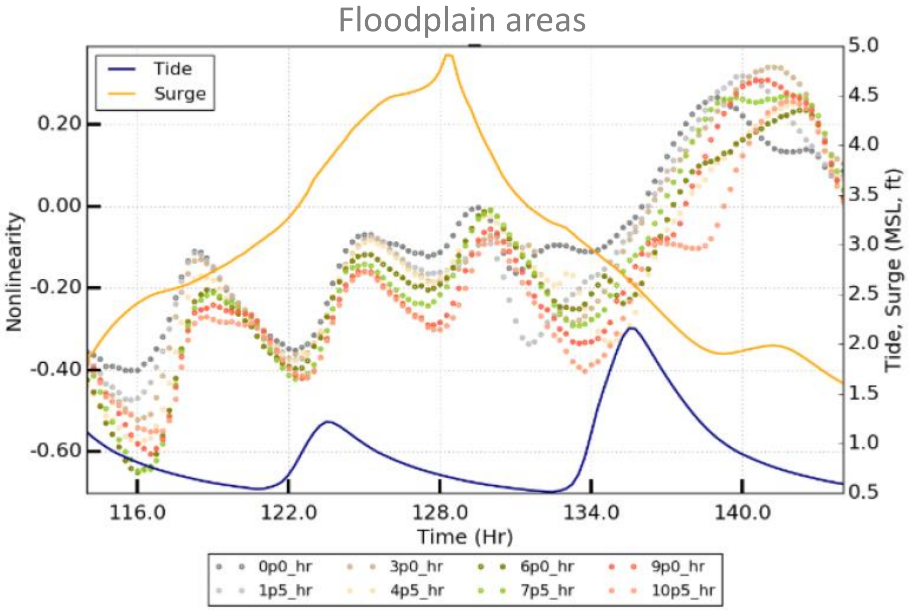
Following Lin et al., 2012, we define the nonlinearity as

$$\gamma = \frac{L}{\eta_{storm} - \eta_{tide} + H_{tide}}$$

with $L = \eta_{storm} - \eta_{surge} - \eta_{tide}$

- 90 degree out of phase from water level; weak near the peak
- irregular in tidal flat areas where nonlinearity is expected to be stronger

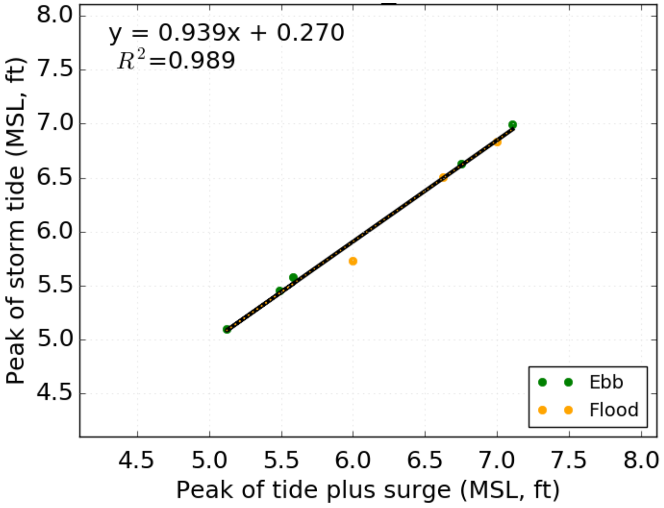




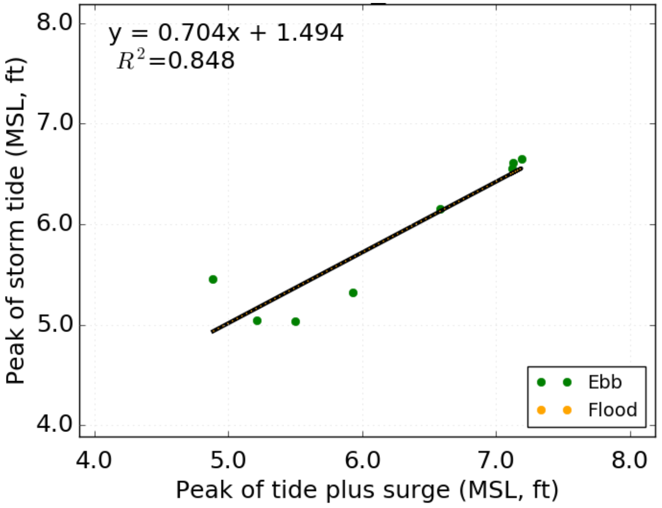
Linear superposition vs direct simulation

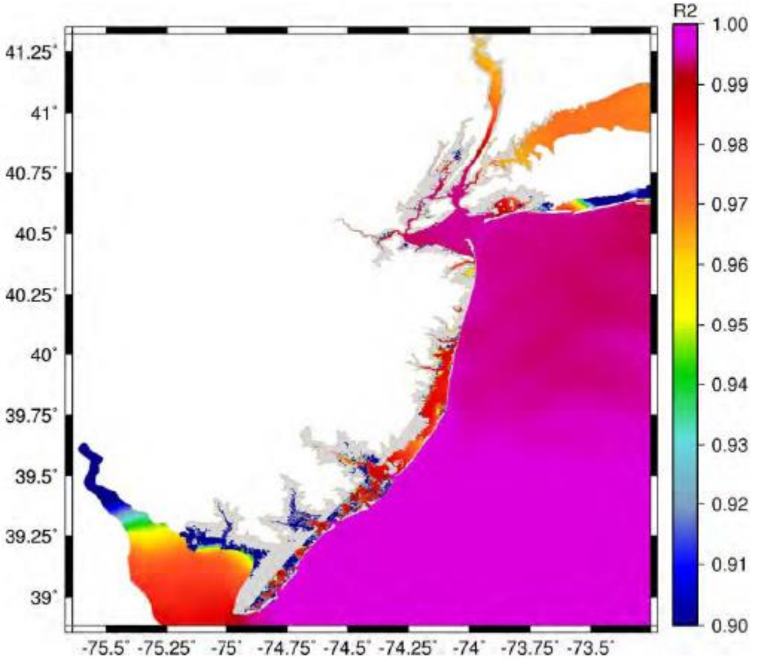
- strong linear correlation in non-tidal flat areas
- nonlinearity reduces the peak water level in tidal flat areas

Atlantic City



Tidal flat areas





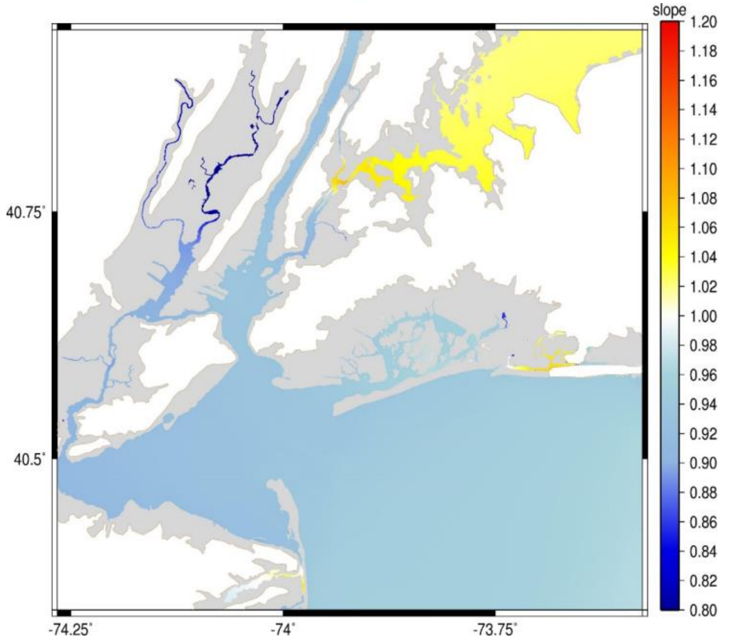


Image credit: Arcadis

Infinite number of peak storm tides can be generated, and sensitivity of the PWL can be analyzed

Bootstrapping

Step 1 – Storm Tide Generation

Consider a fixed number of tide phases, *N*

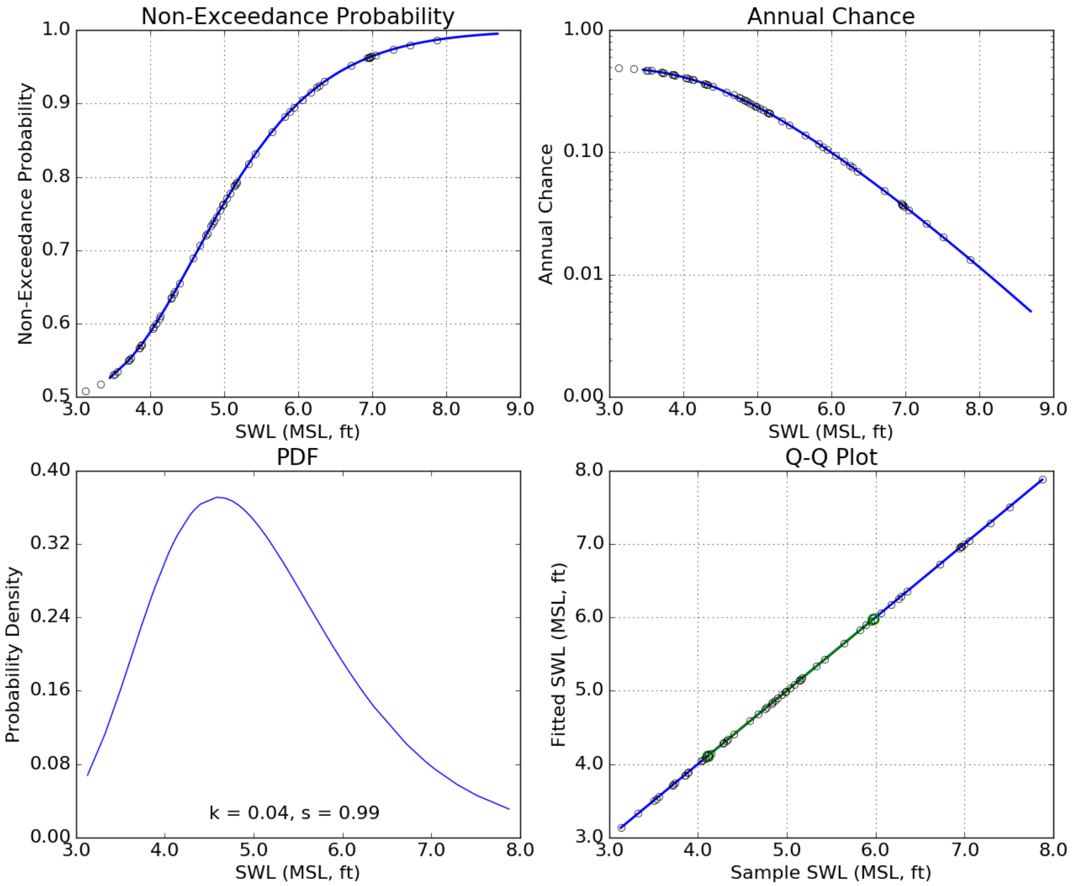
⇒ select *N* tide for each storm random

⇒ *30 * N storm tides by linear super-position with the peaks being adjusted by the regression equation*

Step 2 – Return Period Analysis

A return period analysis is performed by fitting the peaks of all storm tides to the generalized extreme distribution (GEV)

Atlantic City



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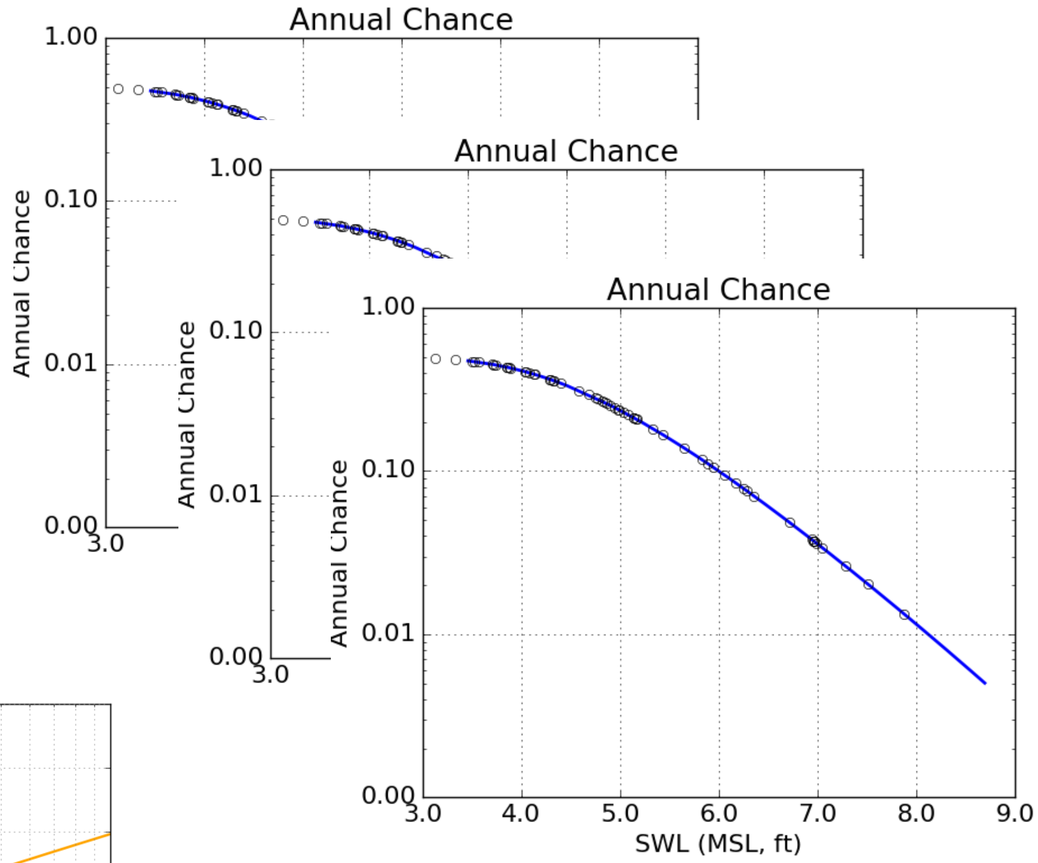
Bootstrapping

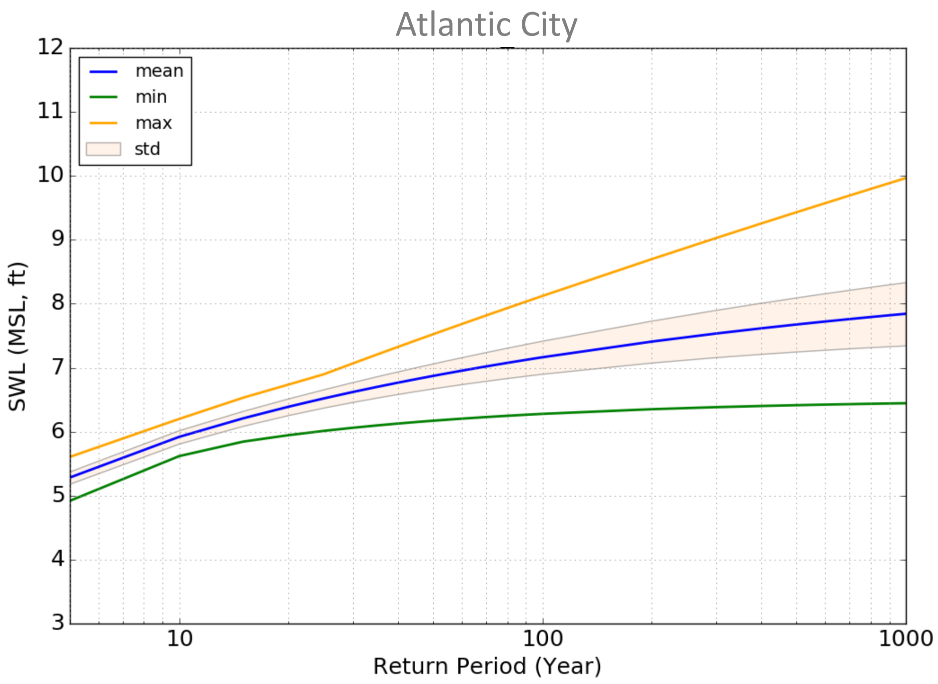
Step 3 – Bootstrapping (fixed *N* random tide)

Repeat a sufficiently large number of

- Step 1 – Storm tide generation
- Step 2 – Return period analysis

⇒ consistent sample mean and standard deviation of the PWL due to random tide selection with *N* tidal phases.





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Bootstrapping

Step 4 – Bias due to Number of Tide

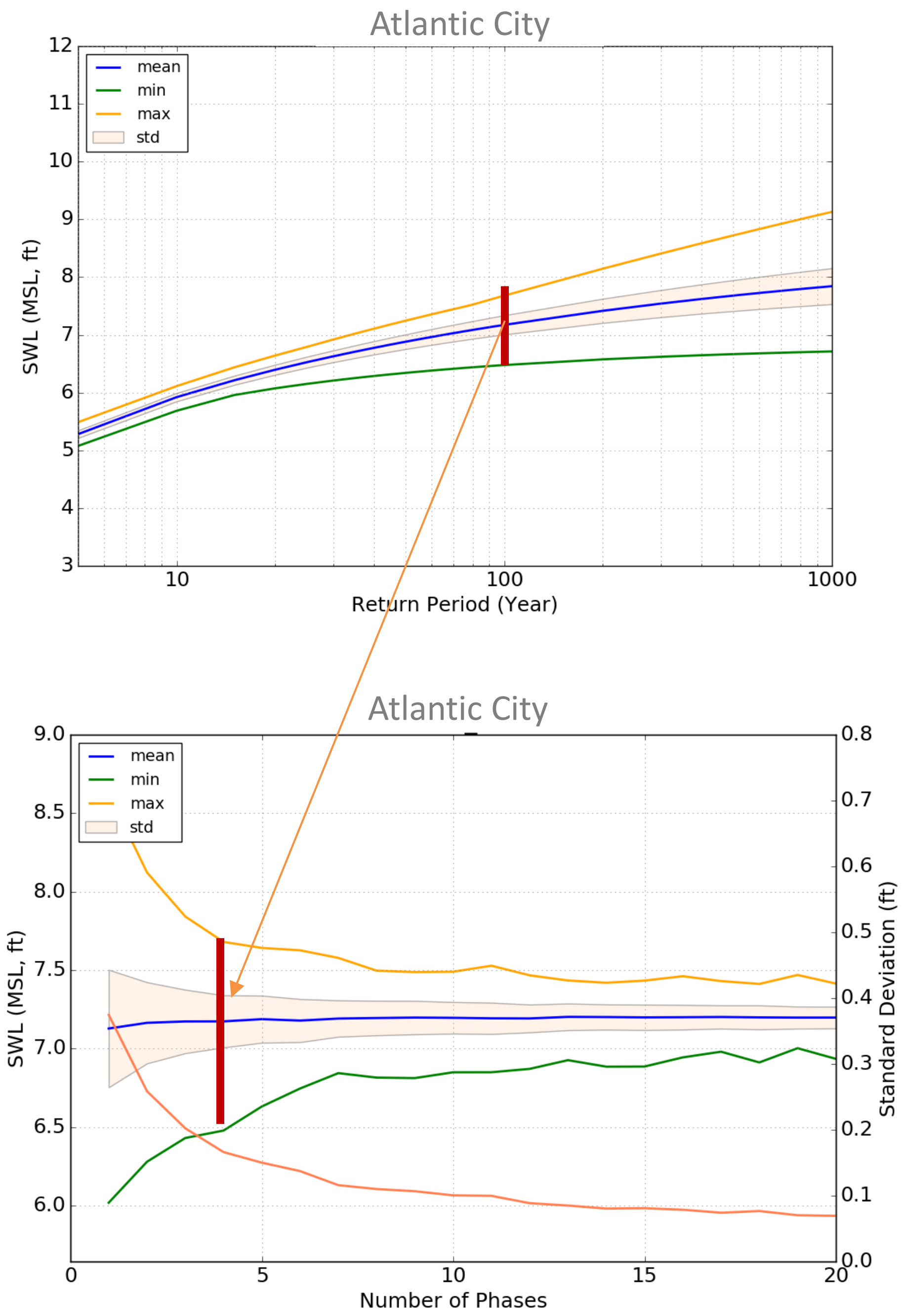
Increment the number of tidal phases *N* and repeat

Step 3 – Bootstrapping
(Step 1 and 2 imbedded)

⇒ sample mean and standard deviation of the PWL for each *N tides* (shown for 1%) .

The sufficient number of tidal phases can be determined by identifying the point of diminished returns in terms of reducing the standard deviation with increasing *N*.

- Minimal 10 random tides for each storm are required for the standard deviation to converge at practical level
- The variation of 1% WL due to tide is roughly 0.5 ft. within two standard deviations (95% confidence level)



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Summery and Discussion

Summary

- The peak WL of ETS typically occurs near the vicinity of the high tide;
- Nonlinearity of storm surge was analyzed by comparing storm tides from linear super-position and direct simulation, which shows 90 degree out of phase from tide with weak nonlinearity near the peak for non-tidal flat areas;
- Bootstrapping with linear superposition and regression equation shows the bias due to random tide can be greatly reduced by using more than 10 tides, where the reduction of the bias becomes very slow.

Discussion

This approach works well for non-tidal flat areas where nonlinearity is weak, whereas tidal flat areas with strong nonlinearity still relies on direct simulations. However, this approach can be used to guide the selection of the tide conditions for direct simulations rather than random selection to reduce the bias due to the tide.

Q&A

Acknowledgement

This study is funded by FEMA. The outcome of this study only services as a supporting material for FEMA Coastal Flood Risk Analysis, where further detail analysis will be carried out for final decision making.